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ABSTRACT

This chapter describes the corruption of research design and explains why and how a computer-based curriculum innovation project was transformed from a quasi-experimental design to a comparative case study. The first section introduces the Systems Thinking and Curriculum Innovation Network (STACI) that examined the impact of technology on teaching and learning activities and illustrates how the comparative case study methodology was developed, expanded, and adapted both to facilitate an educational innovation and to document its ontogenesis. The second part focuses on methodological issues including the need for longitudinal design, multiple methods, multiple levels of analysis, and system analysis. (KHR)

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8 The Corruption of a Research Design: A Case Study of a Curriculum Innovation Project

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This chapter describes the corruption of a research design. It explains why and how a computer-based curriculum innovation project was transformed from a quasi-experimental design to a comparative case study. The project, the Systems Thinking and Curriculum Innovation Network (STACI^N), is a multiyear curriculum development, implementation, and research effort conducted by the authors, who are research staff members at Educational Testing Service (ETS). The project examines the impact of technology on teaching and learning activities (Mandinach & Cline, 1994a). More specifically, the STACI^N Project implements systems thinking and systems modeling in precollege curricula and examines their impact on:

- Student learning processes and outcomes.
- Classroom dynamics and teachers' behavior.
- The organizational structure and functioning of schools.

The first section of this chapter tells the story of how the STACI^N Project evolved over 8 years, drawing specifically on anecdotes and data that illustrate how the comparative case study methodology was developed, expanded, and adapted both to facilitate an educational innovation and to document its ontogenesis. The second part of the chapter focuses on methodological issues, including the need for longitudinal design, multiple methods, multiple levels of analysis, and systems analysis.

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THE STORY OF THE SYSTEMS THINKING PROJECT

Objectives

The STACI[N] Project began in 1986. It was funded by the Office of Educational Research and Improvement (OERI) of the U.S. Department of Education and a collaboration between ETS and the Educational Technology Center (ETC), located at the Harvard University Graduate School of Education. The original purpose of the STACI[N] Project was to examine the impact of technology on students' acquisition and transfer of higher order thinking skills, using system dynamics as the instructional vehicle. As defined by Hulse (1995):

> System dynamics is the study of how the behavior of systems arises from the mutual interactions of their component parts and processes. The need to understand such behavior is ubiquitous—a common intellectual thread unifying the study of the sciences, technology, economics, business, social systems, etc. (p. 2)

At the time, system dynamics seemed to be a promising choice because it had the potential to stimulate the acquisition of important cognitive skills, was generic in nature, and had not been used extensively at the precollege level yet.

The field of system dynamics was created by Jay Forrester (1968), with the Sloan School of Management at the Massachusetts Institute of Technology (MIT). Drawing on their experiences in creating computer models of assembly line manufacturing, Forrester, his colleagues, and students developed a simulation and modeling language, DYNAMO, for mainframe computers that allowed them to create models of many economic and social systems. The titles of Forrester's books, starting with *Industrial Dynamics* (1961), continuing with *Principles of Systems* (1968), *Urban Dynamics* (1969), and eventually *World Dynamics* (1971), document the expanding complexity and scope of the simulations produced by the MIT group.

In 1985, Barry Richmond, a student of Forrester's, developed a Macintosh microcomputer version of DYNAMO called STELLA (Systems Thinking Experiential Learning Laboratory with Animation). Richmond established his own company, High Performance Systems (HPS), in New Hampshire, to market STELLA (Richmond, 1985) and produce new software to facilitate modeling and simulation. With the implementation of system dynamics principles on microcomputers, the capability of developing models and using simulations for instruction

became available to any teacher and school able to afford the relatively inexpensive Macintosh computer. A computer-based, curriculum innovation project using systems thinking suddenly became an affordable possibility.

The systems thinking approach, as operationalized in the STACI^{N} Project, consisted of three interdependent components:

- The theoretical perspective of system dynamics.
- The graphical user interface computer (GUI), at that time the Macintosh.
- The simulation and modeling software package STELLA.

The systems thinking approach was viewed as an instructional tool that could be integrated into curricula to facilitate students' acquisition of declarative and procedural knowledge.

Project Inception

The systems thinking project began with the establishment of a mutually beneficial collaboration among three parties: ETS, ETC, and Brattleboro Union High School (BUHS) in Vermont. ETC was seeking a meaningful role for ETS as a part of their collaboration. ETS had conducted an extensive survey of educational software in pursuit of a program that would engender higher order thinking skills across the curricula. In the summer of 1986, we at ETS were introduced to STELLA and systems thinking. We recognized its potential for instructional enhancement immediately. Concurrently, we learned that BUHS was planning to use STELLA in its science department. BUHS had applied for and received a U.S. Department of Education Secretary's Discretionary Grant to support its implementation of systems thinking. Four enthusiastic teachers were ready to implement systems thinking by the beginning of the 1986-1987 academic year.

The four teachers at BUHS who had applied for the grant were thrilled to receive $20,000. Initially, it seemed like a great deal of money. However, it soon became clear that they had underestimated substantially the time, money, and resources that would be needed to develop and introduce systems thinking in their classes. At that time, faculty, students, and parents had received only limited exposure to systems thinking, which was initiated by an interested parent who had studied under Forrester. The teachers needed substantial and sustained support for learning systems thinking and the use of STELLA. Very few materials for systems-based

curricula at the precollege level existed. The teachers would have to develop any materials that they needed, and they would have to consult with experts to help in that development process. Also, the school had only three Macintosh computers on which to run STELLA. More computers would be needed if the teachers were to begin using systems thinking on a broad scale. All these activities would require a good deal of time and money. Time was required to come up to speed with systems thinking and STELLA, to begin to develop curricular materials, and then to implement them in their classes. Money was required to support the requisite resources and to pay for the staff time. Although the teachers did not recognize it then, BUHS faced a virtually impossible task.

ETS was seeking a platform that would enable it to conduct research on the impact of technology. BUHS provided such a platform. With financial support from OERI through ETC, ETS could provide BUHS with the resources to use technology in their classrooms. The External Research Division at Apple Computer, Inc. donated 15 Macintosh computers to BUHS. With the funds from ETC, the teachers were paid stipends and provided with opportunities to learn systems and STELLA. A system dynamics expert from MIT paid frequent visits to BUHS to work directly with the students and teachers on modeling techniques. Support for systems thinking was given to the project by the BUHS principal, superintendent, and school board. ETS also was authorized to conduct a research study examining the impact of systems thinking on the students, teachers, and the school. Seemingly, everything that was needed to facilitate the implementation of and research on systems-based curricula was in place. Thus, the original STACI Project was launched. Little did we know that it would be a long time before we could do any research on its impact.

A Rocky Beginning

ETS worked exclusively with BUHS for 2 years, with the assistance of the system dynamist from MIT and the staff of HPS. We were implementing what we thought was an almost perfect quasi-experiment. Systems thinking would be introduced into the science courses taught by the four project teachers; other science department members would serve as the controls. Although students were assigned randomly to systems or traditional courses, there was no reason to suspect any bias. As envisioned, we would be able to compare students who had taken systems-based courses with their counterparts who had received traditional instruction. Furthermore, over successive years, we hoped that we would be able to obtain data

about the transfer of systems thinking skills as students progressed through the science curricula.

By Halloween of 1986, we realized that it would be impossible to integrate enough systems thinking materials into BUHS's science courses to enable us to detect any impact on students' learning by the end of that first academic year. While juggling their normally heavy load of academic and administrative responsibilities, the teachers were trying furiously to develop new materials. They had neither the time nor the energy to achieve their new pedagogical objectives. The materials that did get produced were completed with substantial assistance from the MIT and HPS consultants, and they were plagued with many pedagogical problems. The consultants had little experience with precollege instructional materials, and the teachers had not developed yet a feel for what systems topics might be readily applicable to high school curricula. The teachers selected topics that, when translated into systems models, were far too complicated for their students. Furthermore, the teachers held such high expectations for their students' achievement that the tests they devised were too difficult. There was a huge chasm between expectations and outcomes, causing the students and their teachers to become frustrated. This frustration sabotaged the effective use of systems thinking for both the students and the teachers. The teachers had failed to make the educational objectives of systems thinking clear to their students. Consequently, many students perceived it to be irrelevant, abstract, or too difficult.

As we tracked the progress or lack thereof at BUHS, a number of issues became apparent. First, it made no sense at all to conduct research on the impact of systems thinking until there was a critical mass of instructional materials being used in the classrooms, and this was not going to happen quickly. Second, the quasi-experimental design was not appropriate. What was needed was a more flexible research design, closer to what Newman (1990) later termed the formative experiment. Third, the teachers needed more time, support, training, and colleagues with whom they could collaborate. Fourth, a few teachers in rural Vermont could not promote a substantial growth in materials for systems thinking curricula. Fifth, the research project needed to be preceded by a concerted effort to develop and implement the appropriate curricula. Then, and only then, could the research occur.

Sixth, the role of the teachers needed to change from those who impart knowledge to their students to facilitators, mentors, and coaches. Finally, we, the researchers, realized that our

roles had changed rapidly from objective observers to involved participants. Despite the minimal implementation, we recognized the potential that systems thinking had for the improvement of teaching and learning activities. In the process of helping with the project's implementation, we had become participants and colleagues. The questions that confronted us were how we could help the teachers at BUHS best, implement systems thinking more effectively, and study its impact on students' acquisition of knowledge, classroom dynamics, and organizational change.

Project Expansion

Encouraged by what we had learned from the project thus far, we began to explore the feasibility of expanding it. The issues mentioned previously intrigued us, and we wanted to pursue them. ETC's funding was ending, and we needed to seek additional sources of support. Concurrently, we needed to conceptualize a project that would build on what we had learned during the two years at BUHS and to move forward. With additional assistance from the External Research Division at Apple and ETS, we created a consortium of schools whose teachers formed collaborative content teams to develop, share, and implement systems-based, instructional materials. We needed a critical mass to build on the BUHS experience and to work with those teachers to produce materials in a number of content areas.

Recognizing the potentials of the instructional perspective, Apple wanted to provide additional support, but requested that the schools be located in the Silicon Valley. We sought schools that varied along a number of dimensions: the academic aspirations of the students, administrative commitment, and the ethnic and socioeconomic characteristics of the community served. We wanted to explore those characteristics of students, schools, and communities that might either facilitate or impede the implementation of such technology-based innovations in the curricula.

In spite of uncertain funding at that time, four high schools and two middle schools in the San Francisco Bay Area agreed to work with us. In each school, a minimum of five teachers volunteered to participate. Thus, the STACI^{N} Project was launched as an extension of STACI. The superscript N denotes the fact that the teachers formed a network of collaborators. Apple again provided hardware to the schools, but, this time it donated much more equipment. Each school received 20 Macintosh microcomputers, 15 for a school laboratory and 5 for the personal use of the teachers. HPS also agreed to continue to serve as instructors in systems thinking, modeling, and STELLA for the teachers as well as to be available as on-call expert

consultants for the entire project. The teachers' workshops became more formalized, structured, and extensive. HPS learned from STACI^{N} how to work effectively with precollege teachers, and the STACI^{N} participants received regular and ongoing instruction, consultation, and guidance about modeling and the integration of systems thinking into their courses.

Perhaps most important, the teachers had a number of colleagues with whom they could collaborate. Originally, we thought that the teachers would align themselves by their content areas with, for example, the biology teachers working together. This happened sometimes, although not as frequently as expected. Some teachers preferred to form school teams or cross-disciplinary groups. Whatever the structure, the project had teachers from seven schools (and, ultimately, an eighth school, a high school in Tucson, Arizona) coming together at least twice a year to implement the systems thinking approach in their classes. Furthermore, all the schools were connected by a project-sponsored electronic mail network that allowed the teachers to communicate, share curricular materials, and discuss progress and problems.

Lessons Learned

Six additional years of funding from various U.S. Department of Education awards and contributions from ETS sustained the project's work. During that time, the project involved almost 100 teachers into whose classes the systems thinking approach was integrated. The approach worked for most teachers, but failed to match pedagogical objectives for others. In the successful applications, teachers were able to implement systems thinking in such a way that its use enhanced teaching and learning activities in their classrooms. Systems thinking stimulated students' acquisition of declarative and procedural knowledge as well as increased their level of motivation and cognitive engagement. The approach provided teachers with fresh ways of presenting topics that had been difficult to structure formerly. Regardless of their level of expertise and experience, the approach also stimulated the teachers' professional development. Many of the teachers reported that the use of the systems approach had sparked a new level of enthusiasm for their careers. It gave them novel ways of presenting materials as well as access to a powerful technology.

In contrast, approximately one third of the teachers found the use of systems thinking too difficult, labor intensive, intrusive, or contrary to curriculum mandates, accountability factors, or pedagogical styles. Therefore, they resigned from the project. The reasons for some of these

failures are informative. To implement the systems thinking approach effectively as it was defined originally, teachers needed to be facile not only with a GUI computer and the STELLA software, but also with the theory of system dynamics. Overcoming computer phobia was a hurdle for some teachers. Mastering the software was an issue for others.

The most difficult tasks for the unsuccessful teachers were to recognize how the systems thinking approach could be applied to their subject area and then to design curricular modules and systems models based on that understanding. Although many of the teachers acknowledged the potential applicability, they had difficulty translating it into workable curricular materials. Some of them wanted to be handed packaged curricular materials rather than to develop them on their own. The process of becoming a proficient systems thinking teacher, particularly for some of the early participants, required more time and effort than they were willing or able to devote.

This particular problem began to diminish when curricular materials became more readily available and the teachers had colleagues with whom they could collaborate. In addition to increases in the critical mass of materials and colleagues, there had been substantial enhancements to STELLA, making it more user friendly. Furthermore, STELLA was not the only systems-based software available. Other modeling tools had come on the market. Also, some teachers started using the series of simulations produced by Maxis that included SimCity (Maxis, 1989) and SimEarth (Maxis, 1990). These software packages are based on the principles of system dynamics too, albeit in a more "edutainment-like" format. Moreover, teachers can obtain systems thinking training courses from HPS and other organizations now. There are increasingly more and better resources at teachers' disposal to enable them to adopt systems thinking.

Some teachers saw an immediate fit for systems thinking in their curricula. For others, the fit was not readily apparent. In some instances, the course content was structured so tightly that no more material could be squeezed into the curriculum. These teachers perceived the use of systems thinking as forcing the removal of some previously mandated material. In other words, if systems thinking were introduced, other content would have to be sacrificed. In contrast, those teachers who used systems thinking effectively, saw it as an enhancement to the existing curricula, not as an additional component. They used the approach to teach topics that heretofore had been difficult or could benefit from a new instructional perspective. They did not have to sacrifice existing course content in favor of systems thinking.

However, the pressure to cover the curriculum in light of accountability to prescribed goals is a very real phenomenon, particularly at the high school level and for advanced placement courses. Schools use standardized test scores for a variety of reasons. However, teachers frequently think that their performance evaluations are based on the test scores of the students in their classes. We found that a number of the STACI^N Project teachers who were teaching high-stakes courses in highly competitive schools were among those who embraced systems thinking most enthusiastically. They saw it as a way to increase their students' learning. As an aside, several teachers advised that some of the most able students preferred traditional instructional methods. The better students knew how to succeed under the previous conditions, and they opined that the systems thinking approach required too much work, effort, and thought.

However, many of the teachers who worked at the other end of the ability spectrum also embraced systems thinking, but for very different reasons. Traditional instructional methods had been unsuccessful with their students. These teachers reported that the systems thinking approach engaged students in content areas that were nearly inaccessible using traditional methods. In fact, many of the at-risk students were unable to read textbooks, but they could learn from the GUI computer and the systems-based, curricular modules.

It also became apparent that certain pedagogical styles either impeded or facilitated the use of a constructivist approach such as systems thinking. Generally, teachers who were able to create a constructivist learning environment were effective in implementing the systems thinking approach. One of the more major changes in pedagogical style observed among teachers involved in the project was a shift from teacher-directed to learner-directed environments, in which students became active participants in the educational process. One measure of effective teachers is the ability to relinquish control of the classroom, shifting from being a transmitter of knowledge to becoming a facilitator of learning. Such teachers encourage intellectual exploration on the part of their students, focusing on the acquisition of procedural knowledge and problem solving skills, and their application to real-world situations.

Teachers who had difficulty adapting to the constructivist approach were unwilling to allow students to assume responsibility for their learning. These teachers preferred to maintain a didactic classroom environment in which students adhere to the more traditional, passive

role. We refer to this as the funnel method of instruction in which teachers serve as the transmitters of information and students as the passive receptors of it. The teachers' role is to fill their students' heads with facts and figures, and the students' role is to allow their heads to be filled passively. One can imagine a funnel attached to a student's head into which the teacher pours the facts. Many students are frustrated by this method of instruction. The reaction to it of our students in the school in Tucson was to develop the motto, "No More Funnels!"

We believe that the systems thinking approach will decrease the funnel method by engaging students to pursue learning in an active, "hands-on" manner. Students become more engaged and, therefore, more likely to learn more effectively. Many teachers also benefit from the constructivist approach because it infuses excitement into teaching and learning activities. Despite being labor intensive and more work than traditional methods, most of our teachers advise that the systems thinking approach has brought renewed enthusiasm to their classrooms and has stimulated professional development.

It is clear from the preceding description of the STACI^{N} Project that the application of a quasi-experimental research design to it was neither sufficiently sensitive nor powerful enough to be fruitful. The overriding evaluation question in many educational innovation projects is, "Does it work?" It is clear from the example of the STACI^{N} Project that this question needs to be refined further and broken into a large number of more explicit questions. For example, what kinds of students have what kind of learning experiences with what types of materials and instructional approaches? Then, each of these questions needs to be subdivided into even more specific questions.

It would be highly desirable if, in the next section of this chapter, we could propose a specific research design for most or, at least, many of these questions. However, in our view, it would be premature to suggest such designs. We feel strongly that it is necessary to apply multiple perspectives to a project of this sort. Therefore, rather than finishing the chapter with a description of alternative or more effective research designs, we present a series of observations and inferences relevant to the conduct of such projects.

Methodological Implications

During the eight years of the STACI^{N} Project, the methods used to implement and evaluate systems thinking underwent substantial revision and adaptation. In many respects, we innovated as we implemented, so to speak. Methods were adopted to meet the immediate

needs. Some things, like indepth interviews with teachers and students and classroom observations, produced useful information. Other efforts, such as a cognitive analysis of teachers' think-aloud protocols of model-building exercises, did not prove useful. What emerged gradually was a variety of perspectives and procedures that probably are described best as a comparative case study.

From the experiences recounted earlier, it is possible to infer a number of important methodological implications relevant to the design and execution of a comparative case study that examines the impact of a mathematics and science educational reform project. We find it convenient to classify these inferences in four interrelated categories: (a) longitudinal design, (b) multiple methods, (c) hierarchical analyses, and (d) system dynamics.

In the remainder of this chapter, we discuss these methodological perspectives. However, first, an initial comment: Perhaps the most important lesson we have learned from the STACI^{N} Project is that it is absolutely necessary for researchers to remain flexible in applying their methodological knowledge in a field setting. The common, dominant leitmotif that pervades our discussion here is the obligation to adapt continuously to the needs of the participants in a project. Perhaps those of us who are engaged in educational research projects can learn from the world of business where, today, there is a growing awareness of the imperative to stay attuned to the needs of one's customers.

In educational research we must develop sensitivity to the needs of the participants in our projects, be they students, teachers, administrators, parents, or policymakers at any level. Particularly in the case of educational reform efforts, we may have to change our conceptions about our research activities and think of the participants more as collaborators and colleagues. This transition occurred in our perspectives, particularly of the teachers and administrators in the STACI^{N} Project. As the previous description made abundantly clear, flexibility in meeting the requirements of our colleagues was the hallmark of our efforts.

The STACI^{N} Project did not resemble at all the accounts of research methods found in most social and behavioral science methodology textbooks. It was necessary to make continuous adjustments in all aspects of its implementation and assessment phases. We did have initial hypotheses concerning learning and transfer, but they were set aside quickly as we struggled with all sorts of problems associated with the delivery and installation of hardware and software. In fact, very few of our initial expectations were realized, and we were revising

our strategies, priorities, roles, and schedules continuously in order to accommodate a plethora of unexpected problems and contingencies. Furthermore, during the course of the project, it became necessary to provide a variety of services and assistance to the schools and the teachers.

At different times, we served as hardware installers, technicians, software instructors, troubleshooters, guidance counselors, travel agents, caterers, and even lay psychotherapists. If a researcher makes a commitment to teachers and schools to implement and evaluate computer-based innovations in their curricula, it is not realistic to expect to perform only those activities customarily associated with research, such as subject assignment, data collection, analysis, and scholarly reporting.

Had we been unwilling or unable to take on all the roles just enumerated, the STACI^{N} Project would have faltered in the early months, and one would have been tempted to conclude that another effort at educational reform fell short of its desired objective. Technology-based innovations such as the STACI^{N} Project require the acquisition and installation of hardware and software on the one hand and the continuous support of teachers on the other. Flexibility in applying traditional social and behavioral science research methods has to be complemented with common sense and an orientation to be of service to the students, teachers, and schools participating in the project.

Longitudinal Design

In the application of both methodological expertise and flexibility, it is likely that the researcher will have to sacrifice the quasi-experimental methodological design that has become the idol of so many social and behavioral scientists. Since the publication of the now classic article by D. T. Campbell and Stanley (1963), many researchers have striven to attain or approximate this design. It is an adaptation of the classic laboratory experiment in which all the extraneous conditions that might influence the outcome are supposedly eliminated or controlled by randomization and appropriate data analyses. Indeed, there are many occasions in which this design is appropriate and viable. However, most of the instances involving computer-based innovations in the curricula that take place in real time in classrooms are not amenable to the quasi-experimental design. Two fundamental aspects of the quasi-experimental design were problematical in the STACI^{N} Project: Before and after measurements and the use of experimental and control groups.

Inherent to the concept of the experiment is the requirement that measurements be taken before and after the application of a stimulus or treatment. To have these measurements correspond to before and after states, there must be some specific point or points in when the stimulus or treatment is applied. However, as the earlier description of the STACI^N Project shows clearly, the implementation of systems thinking by the participating teachers was a gradual process that took many years. In each succeeding year of the project, the students enrolled in classes using systems thinking were exposed to more curricular modules that had this dynamic, problem solving perspective embedded. Furthermore, the nature, extent, and effectiveness of those modules expanded each year as the teachers became more knowledgeable and adept in using the systems thinking approach. Therefore, in the STACI^N Project, it was impossible to identify before and after conditions. Rather, there was one continuous process of change.

Corresponding to the teachers' gradual professional development in using systems thinking was the incremental intellectual growth of the students as they applied their modeling and simulation skills in different courses. For these reasons, comparing measurements gathered in the beginning with those collected at the end of any particular school year made no sense. In 1 year, the differences that were detectable were likely to be minimal. The noticeable changes began to appear after several years, particularly when students employed systems thinking in a sequence of science and mathematics courses.

The second feature of the quasi-experimental design that was problematical in the STACI^N Project was the use of experimental and control groups. A canon of all research experimentation is the application of the stimulus or treatment to the experimental group and the withholding of it from the control group. The essence of a quasi-experiment is the random assignment of subjects to these groups. Randomization is assumed to control for all other possible extraneous factors that might be considered to have a causal relationship with the treatment. However, it is essential to the integrity of the design to avoid contamination by preventing any of the treatment occurring inadvertently with the subjects in the control group.

In a laboratory setting, such contamination is avoided more readily. When the research is being conducted in a school setting over several years, it is impossible to block such contamination. For example, in several schools in the STACI^N Project, teachers who were not members of the project became interested in systems thinking and started using some of

the curricular materials in their classes, which we had intended using as control groups. It would have been imprudent to ask those teachers to stop using our materials, and it is quite likely that they would have refused. Administrators in those schools would have been perplexed by such a request, for we had spent considerable time and effort convincing them and their school board members that systems thinking would help their students to learn and their teachers to become more effective. Why, then, would we want to prevent other students and teachers from benefiting from the project as well? In fact, one of the long-range objectives of the STACI^{N} Project is to promote widely the use of the systems thinking approach. It would have been both impossible and contradictory to our goals to obstruct its spread to the control classes in a futile attempt to protect experimental integrity.

Furthermore, during the course of a school year, students would change classes, shifting from what we called experimental groups to control groups and contaminating the design further. In some of the schools, there were huge changes in the composition of the classes during the course of one school year. Several teachers reported that as many as 50% of the students enrolled in a course in the fall would be gone by the spring. A recent statewide study in California documented similar mobility patterns (Lash & Kirkpatrick, 1994). To make matters even more complicated, from one year to the next, students were exposed to an increasingly complex pattern of treatments and nontreatments. Over a 4-year high school or a 7-year middle and high school progression, the mix of experimental and control exposures eventually became unwieldy.

In the previously cited Campbell and Stanley monograph, 16 different designs are discussed, corresponding to various patterns in which subjects are assigned randomly to experimental or control groups and measures of the impact of the treatment are repeated. When the researcher is able to control the introduction of the treatment and their subjects are assigned randomly to experimental and control groups, the quasi-experiment can be assumed to take on most of the characteristics of the true experimental design. However, in the STACI^{N} Project, the stimulus was by no means a single event and the students moved freely into and out of the so-called experimental and control classes.

It is virtually impossible to indicate precisely when the treatment was administered and, therefore, when comparisons between measures would be meaningful. For this reason, the quasi- experimental design as planned for the STACI^{N} Project originally had to be abandoned, and the research design employed was closer to a continuous time series, as also described by D. T. Campbell and Stanley (1963). Today, we would refer to this as an ongoing longitudinal

design. In this research design, multiple data sets documenting the nature of the innovation and its impact on a variety of dimensions are collected, analyzed, and reported in a continuing cycle. In a very real sense, research focusing on the impact of a computer-based innovation to a curriculum should be designed and executed as an ongoing activity. Data collection and analyses should be carried out continuously and indefinitely. Only in this way is it possible to provide timely and regular feedback to refine the treatment further and to enhance teaching and learning.

Multiple Methods

In the early stages of the project, it became clear that incorporating systems thinking would generate multiple impacts, among them how knowledge of a subject is acquired; the development of higher order, problem solving skills; improvement in the students' capabilities for working in groups; changes in the dynamics of the classroom; and professional development opportunities for the teachers involved in the project. All these were legitimate and positive expectations resulting from the introduction of systems thinking. Obviously, different methods would need to be employed to document and describe the nature and extent of these various consequences.

As mentioned previously, no existing assessment instrument was appropriate. During the course of the project, we developed several versions of a paper-and-pencil test that gauged the extent to which the students were mastering the concepts, vocabulary, and problem solving skills of systems thinking. The students' performance on regular tests, quizzes, examinations, and the like were recorded, and the teachers were asked to indicate whether or not they perceived improvements in their students' achievement. Both observations of classrooms and in-depth interviews with teachers were employed at various points. In many classes, students wrote essays on assigned topics, and the teachers and we analyzed their contents documenting the occurrence of systems thinking themes. Also, think-aloud protocols were collected from students while they solved problems.

All these data collection methods provided a rich and diverse set of evidence, documenting changes and advances made in teaching and learning activities. It was clear that the only hope for an adequate description of the many facets of change and innovation that accompanied the introduction of systems thinking was to rely on virtually all the data collection techniques that are available to the social and behavioral sciences. To do less would have resulted in

incomplete documentation of the project. Unfortunately, there is no simple way to integrate all these analyses into an overall metaevaluative summary.

Hierarchical Analyses

As mentioned in the previous discussion, the impact of the systems thinking approach occurred at three different levels: (a) students' learning, (b) classroom dynamics, and (c) the school as a social organization.

Clearly, a systems thinking model of computer-based revisions to curricula would lead us to anticipate changes at these three levels. Thus far in the STACI[N] Project, we have been able to document and describe changes at each of these levels. The more systematic analyses of the data examining relationships across the different levels remain to be completed. For example, it will be interesting to examine the relationship between a student's declarative and procedural knowledge in varying contexts of learner-centered classrooms. The challenge now is to devise methodologies that allow such hierarchical or contextual analyses.

At the first level, the project focused on gathering data that described how students learn and what they do with the knowledge that they have acquired. The focus here was on how learning that reflected systems thinking occurred. We were interested in both declarative knowledge and problem solving skills. The systems thinking pencil-and-paper test, students' essays, course examinations and grades, and think-aloud protocol analyses were all used. Because the teachers collaborated with us in the collection and analyses of data, different techniques were used in different schools at different times. Therefore, there is no analysis that summarizes all the results across all the schools. However, we can report uniform patterns of improved learning in all instances (Mandinach & Cline, 1996).

At the second level, classroom dynamics, we collected data documenting the changing patterns of interactions among students and teachers. The methods of data collection at the classroom dynamics level were structured observations of classes and indepth interviews with teachers. In several instances, teachers observed and recorded activities in each other's classrooms. Because students typically worked in pairs using their systems thinking materials, the teachers lectured to the entire class far less frequently and spent more time working with the dyads providing advice, encouragement, and technical expertise. One of the teachers described this experience as similar to a butterfly pollinating the students' minds by flying around the room and touching down here and there to provide assistance. Many computer-based, educational innovations have noted a shift in classroom dynamics from the traditional

lecture style to a more student-centered, student-directed learning environment (Mandinach & Cline, 1994b).

Of the three levels of analyses in the STACI^N Project, the one of the school as a social organization is the least well developed. The objects of inquiry here are the sociological changes that occur in a school, focusing on its structure and function. The data that do exist for this level so far were collected during interviews with teachers, administrators, and school board members. The analyses will include changing patterns of role performance, interpersonal communication, personal influence, power and authority, and job satisfaction. Future publications will communicate the results of these analyses and explore their policy implications for supporting reform in mathematics and science education.

System Dynamics

By now, it must be clear that the longitudinal, multimethod, hierarchical perspective that emerged over the eight years of the STACI^N Project was system dynamics. Gradually, we learned to apply to the STACI^N Project the same perspective that we were helping the teachers to use in their classrooms. However, this transition caused a strain in our relationships with our funding agencies and sources of support. Many people, including staff in the organizations that supplied the resources for the project, OERI, ETC, ETS, and Apple Computer, as well as the students, teachers, administrators, and school board members, wanted an answer to the question, "Does it work?" Of course, it is an understandable and legitimate question. They all wished to know whether the substantial investment that they are making in the promotion of systems thinking is having the desired, and at least implied if not promised, positive impact. However, as noted previously, the history of the STACI^N Project makes it obvious that this is not an appropriate question.

In fact, in any educational reform project, it is now clear to us that to ask a single question about impact or outcome is naive. Furthermore, to search for the ideal experimental or quasi-experimental design for evaluation research is fruitless. Reform endeavors take place in real-world contexts that are composed of many, interrelated, dynamic factors. Any attempt at educational reform will have multiple components and multiple impacts, and they will interact across levels of organization and over time. Many questions must be asked repeatedly, and the answer to any one of them is almost always related to many others. We need to ask

what the factors are that facilitate or impede effective teaching and learning. The answers to some of these specific questions have been set forth by us elsewhere (Mandinach & Cline, 1994a, 1994b).

In recent years, an appreciation of the need for a systems thinking approach has grown in the educational reform and research communities. A joint undertaking of OERI and the National Science Foundation (NSF) is attempting to promote systemic reform. Each state has been invited to create a comprehensive plan to effect systemic reform of public education from kindergarten through Grade 12. As of this writing, close to 40 states have had their plans approved, and federally funded systemic reforms are underway. Unfortunately, the power of systems thinking is not realized fully in these efforts. NSF offers the following definition:

> "Systemic reform" is a process of educational reform based on the premise that achieving excellence and equity requires alignment of critical activities and components. It is as much a change in infrastructure as in outcomes. Central elements include—high standards for learning expected from all students; alignment among all the parts of the system—policies, practices, and accountability mechanisms; a change in governance that includes greater school site flexibility; greater involvement of the public and community; a closer link between formal and informal learning experiences; enhanced attention to professional development; and increased articulation between the precollege and postsecondary education institutions. (Suter, 1996, p. 5)

Notice that there is no mention of systems analysis in this definition. Simulation and modeling as aids in the analysis of reform efforts are ignored. Although the components of the definition are commendable and there is a call for alignment of the elements of systemic reform, no attention is devoted to the issues of interaction and feedback—the core of systems analysis. Consequently, the discipline, rigor, and precision in planning and assessment that derive from the systems thinking approach are not realized in a project that is devoted to systemic reform. In a recent work, we presented our first draft of a systems thinking model of a computer-based, educational, curricular reform project (Mandinach & Cline, 1994a). FIG. 8.1 is a revised draft of that model.

It contains a proposed set of variables describing the components of changes fostered by computer-based revisions to curricula at the student learning, classroom dynamics, and organizational change levels. This diagram is useful as an early approximation of the many factors involved in an educational reform venture such as the STACI^{N} Project. However, it

should be pointed out that FIG. 8.1 is not a STELLA model of the STACI[N] Project. Rather, it is a preliminary step to a model. In the vernacular of STELLA, it is a map, which will be elaborated on and converted to an operating model subsequently.

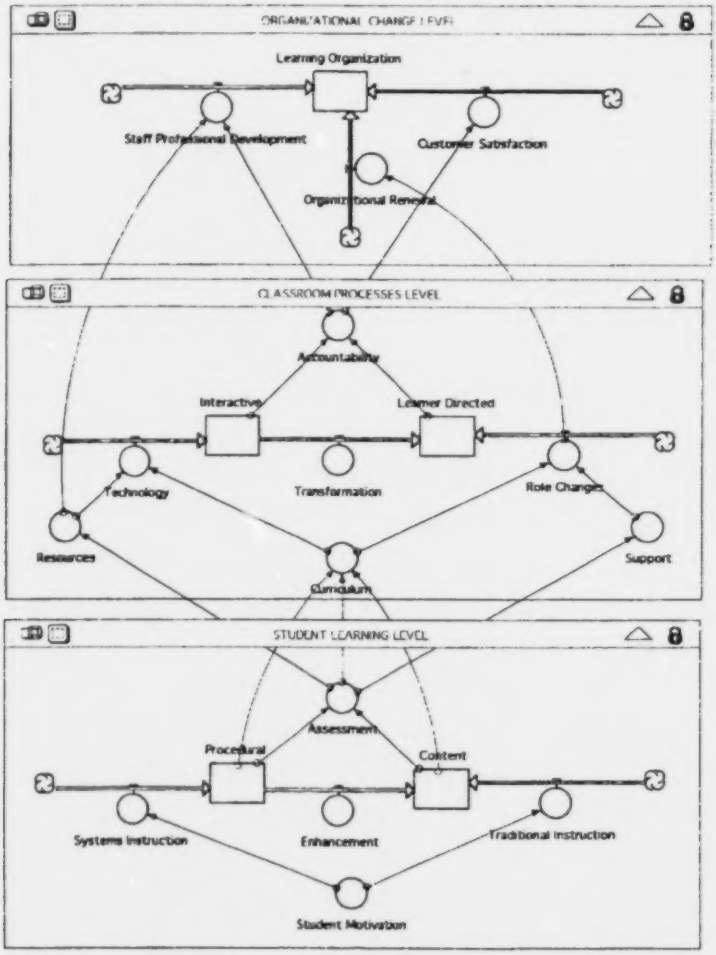

FIG. 8.1. A systems thinking model of a computer-based educational, curriculum reform project.

This chapter is not the appropriate place to present a detailed description of our map. The interested reader is referred to our original presentation (Mandinach & Cline, 1994). Here, we provide a brief overview to give a sense of the power of the systems thinking approach in

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analyzing dynamic phenomena. The STELLA language employs four elements for defining models: stocks, flows, converters, and connectors. Stocks are repositories where accumulations occur and are represented in the map as rectangles. Flows are the regulators of the accumulations and are depicted as pipes with valves attached. Converters and connectors provide the linkages among the stocks and flows and are portrayed as circles and arrows. An analogy to grammar is that stocks are the nouns, flows are the verbs, and converters and connectors are the modifiers or adjectives and adverbs of the STELLA language.

The first level of the map—student learning—depicts two stocks: procedural and content knowledge. The second level of the map—classroom dynamics—also has two stocks: interactive and learner-directed environments. The third level—organizational change—contains only one stock: the learning organization. As depicted in the map, all the stocks are regulated by various flows, converters, and connectors. Notice that there are numerous instances of connectors across the three levels, denoting contextual relationships. For example, the two stocks at the student learning level—procedural and content learning—are connected to the converter, curriculum, at the classroom dynamics level. Also, the flow—staff professional development—at the organizational change level is connected to both the resources and the accountability converters and the interactive and learner-directed environments stocks at the classroom dynamics level.

It should be pointed out that, as in all simulation activities in the STACI^{N} Project, the objective is to facilitate the analysis of the problem, not to create the correct model. This point stresses that our interest in systems thinking is not to get the right model for the purpose of prediction. Rather, it is the heuristic value of creating the model that excites us. Students and teachers alike all report gaining a deeper understanding of the phenomena they are studying through the use of systems thinking. Therefore, we never attempt to find the correct answer. It probably is not attainable, and there would be no way of ever testing its accuracy. Rather, it is the search for a reasonable model that approximates the data available that is an incredibly rich and stimulating experience for all learners.

SUMMARY

In this chapter, we have guided the reader through a description of our activities over an eight-year period in which we carried out innovations to curricula using computer-based curriculum technology. During that time, we took on many roles in addition to that of

researcher to facilitate reform. The efficacy of the innovation depended heavily on the teachers' capability to integrate use of the theoretical perspective of systems thinking, the hardware, and the software in their classrooms. Therefore, we had to spend enormous amounts of time and resources on implementation issues. Most of what we did in the early period pertained to administrative and technical issues, rather than research activities. Also, because it took much longer than we or the teachers anticipated to make systems thinking operational, there never was a time when we could say that the experimental stimulus or the treatment had been administered.

Consequently, our plans for a quasi-experimental design had to be replaced with a more comprehensive case study perspective. We adopted a variety of methods on a continuing or longitudinal basis to examine a host of outcomes from the curricular innovation at three different levels: student learning, classroom dynamics, and organizational change. In all these administrative, technical, and research aspects it was necessary to be adaptive, flexible, and patient. These are skills that are rarely, if ever, discussed in methodology textbooks. In the case of the STACI^{N} Project, they were developed in the field and just-in-time. In many respects, our experiences mirror closely those reported by Newman (1990) in his attempts to use electronic networks connecting schools for teaching and research activities with elementary school students in learning geography. We strongly suspect that such experiences will become commonplace as more endeavors are initiated to use technology to support reforms in mathematics and science education. Editors' note: Since this chapter was first written, significant reformulations have occurred in NSF's systemic reform programs.

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